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“Flame Spectra observed at Swedish Bessemer Works.” By C. J. LUNDSTRÖM, Örtofta, Sweden. Communicated by Professor W. N. HARTLEY, F.R.S. Received April 1,—Read June 20,—Revised October 18, 1895.

*Introduction.*

As no examinations of the Bessemer flame from Swedish steel works had been previously made, I resolved, some years ago, to devote attention to this subject, in order to see to what extent the Bessemer spectrum in Sweden differs from those of other countries, and partly to ascertain whether the spectroscope might be of any practical use in examining the Bessemer “blow.”

My observations were made at the following Bessemer works:—Nykroppa, Hagfors, Långshyttan, and Ulfshyttan and partly also at Domnarfvet.

Embracing the present opportunity, I beg to be allowed to express my thanks to all the managers and engineers of these works for the courtesy I have met with. Especially I am gratefully indebted to Mr. Martin Nisser, the manager of the Klosters Iron Works, for the interest he has shown in procuring a spectroscope adapted to the requirements of this investigation, which he placed at my disposal.

This instrument was a Hofmann's "spectroscope à vision directe avec six prismes," from Paris, consisting of a collimator, six prisms, a telescope, one eye-piece, and a side tube with a scale. The scale is lighted by a lamp, and the degrees of the scale are reflected by the first prism into the eye-piece, which can be moved by a screw so that the different parts of the spectrum may appear in the field successively.

To show the excellence of the instrument, the following facts may be noted. It divides the line  $b$  of the sun spectrum. The distance between  $\text{Li } \alpha$  (6705) and  $\text{Na } \alpha$  (5895) was  $41^\circ$ . The same band showed on the scale the following values:— $42.3$ ,  $42.0$ ,  $42.5$ ,  $42.0$ ,  $42.0$ ,  $42.2$ . By means of an interpolation curve, the wave-lengths of this band were determined to be as follows:— $5351$ ,  $5354$ ,  $5350$ ,  $5354$ ,  $5354$ ,  $5352$ . The interpolation curve was made by numerous observations on the lines of the sun spectrum, the wave-lengths of which were taken from Ångström's atlas. By means of this instrument all the spectra, except those of Hagfors and Nykroppa, were observed. The spectra of Hagfors and Nykroppa were examined by a spectroscope of General Wrede's construction, belonging to the Royal Swedish Academy of Science, which instrument proved, however, to be less suitable for my investigations.

During the Bessemer "blow" there are, as is well known, three periods.

The first is the so-called "slag period," during which in all cases there is only a bright continuous spectrum visible. Just at the beginning of the second period, the "boil," there appears at all the works under my observation, with exception of Långshyttan, first the sodium line, and then a beautiful band-spectrum, which gradually becomes more distinct. It attains its full brilliancy after the entrance of the third period or "fining stage," and then its brightness gradually fades until, upon complete decarbonisation, it vanishes. It is this spectrum that in the following pages I propose to designate the "Bessemer spectrum," and to particularise the Långshytte, Domnarfs, Nykroppa, Hagfors, or Ulfshytte spectrum according to the name of the works where the spectra were studied.

At Långshyttan, as at several other works, the flame seems during the transition from the first period to the "boil" to assume a more or less intensely blue colour which soon vanishes, after which the colour becomes more of a milky white appearance.

This *blue flame* gave at Långshyttan a beautiful spectrum, which appeared suddenly and almost immediately in its full brightness, after which it rapidly lost its colour and changed to a common Bessemer spectrum. This I propose to call the spectrum of the *blue flame*, and to describe it separately. At Ulfshyttan the metal "blown" contained a comparatively very large percentage of silicon

with a small proportion of manganese, and the spectrum differed very materially from the other spectra. I shall therefore describe it separately.

I now pass to the description of Bessemer spectra from Långshyttan, Domnarfvet, Nykroppa, and Hagfors. These in general have the same characteristics, and only in unimportant details do they differ from each other.

# I.

## *The Långshytte Spectrum.* (Fig. 1, spectrum I.)

The following table of wave-lengths shows the different aspects of the twenty lines and bands that I observed at Långshyttan. In this and the following table given under the column  $n$  the number of the observations on which the value of  $\lambda$  is based,\* and under the heading of  $\pm\Delta$  the presumable error.

Every one of the  $n$  observations,

$$\alpha_1, \alpha_2, \alpha_3, \dots \alpha_n,$$

have been reduced by means of the interpolation curve to the wave-lengths.

$$\lambda_1, \lambda_2, \lambda_3, \dots \lambda_n,$$

$$\lambda = \frac{\lambda_1 + \lambda_2 + \lambda_3 + \dots + \lambda_n}{n}.$$

If

$$\delta_1 = \lambda - \lambda_1,$$

$$\delta_2 = \lambda - \lambda_2,$$

$$\dots\dots\dots$$

$$\dots\dots\dots,$$

and

$$\delta_n = \lambda - \lambda_n,$$

and if

$$\delta = \delta_1^2 + \delta_2^2 + \delta_3^2 + \dots + \delta_n^2,$$

then  $\pm\Delta$  is calculated from the formula

$$\pm\Delta = \pm 0.674 \sqrt{\frac{S}{n(n-1)}}.$$

In the fourth column the supposed origin of the lines and bands is indicated.

\* In the description of the Långshytte spectrum,  $n$  = the sum of all observations made on the particular bands indicated.

In the table of the blue flame spectrum,  $n$  is the number of observations on the respective bands during only that period when the blue flame appeared.

|     | n.                | λ.     | ± Δ.  |                                | Notes.  |
|-----|-------------------|--------|-------|--------------------------------|---|
|     | —                 | 6705   | —     | Li                             | Strong line; always seen.   |
| α { | 4                 | 6252   | 3·2   | Mn <sub>2</sub> O <sub>3</sub> | Three red lines of strong bands on a continuous bright background.  |
|     | 3                 | 6208   | 2·9   | Mn <sub>2</sub> O <sub>3</sub> |   |
|     | 5                 | 6176   | 1·24  | Mn <sub>2</sub> O <sub>3</sub> |   |
|     | —                 | { 5895 | —     | Na                             |   |
|     | —                 | { 5889 | —     | Na                             |   |
| β { | β <sub>3</sub> 4  | 5855   | 0·65  | Mn <sub>2</sub> O <sub>3</sub> | Fine band.  |
|     | 1                 | 5823   | —     | K                              | Faint line.   |
|     | 1                 | 5781   | —     | K                              | Faint line.   |
|     | β <sub>2</sub> 3  | 5608   | 0·0   | Mn <sub>2</sub> O <sub>3</sub> | Green band shading away towards the red.  |
|     | β <sub>1</sub> 20 | 5581   | 0·9   | Mn <sub>2</sub> O <sub>3</sub> | Strong broad green band shading away towards the red; the brightest band of the spectrum.   |
|     |                   |        |       |                                | Distinct bands; γ <sub>2</sub> appears as a double line; γ <sub>1</sub> terminates this group, shading away towards the red.              |
| γ { | γ <sub>3</sub> 12 | 5426   | 0·84  | Mn <sub>2</sub> O <sub>3</sub> | Equally broad and bright bands, δ <sub>1</sub> forms a natural boundary of the group.   |
|     | γ <sub>2</sub> 14 | { 5389 | { 0·5 | Mn <sub>2</sub> O <sub>3</sub> |   |
|     |                   | { 5387 |       | Mn <sub>2</sub> O <sub>3</sub> |   |
| δ { | γ <sub>1</sub> 21 | 5353   | 0·5   | Mn <sub>2</sub> O <sub>3</sub> | The bands of this group always appear very indistinctly and are only of short duration. The group seems to shade away towards the violet. |
|     | δ <sub>4</sub> 12 | 5264   | 1·24  | Mn <sub>2</sub> O <sub>3</sub> |   |
|     | δ <sub>3</sub> 14 | 5227   | 0·7   | Mn <sub>2</sub> O <sub>3</sub> |   |
|     | δ <sub>2</sub> 15 | 5189   | 1·1   | Mn <sub>2</sub> O <sub>3</sub> |   |
|     | δ <sub>1</sub> 16 | 5160   | 0·9   | Mn <sub>2</sub> O <sub>3</sub> |   |
| ε { | ε <sub>1</sub> 3  | 5103   | 3·9   | Mn <sub>2</sub> O <sub>3</sub> |   |
|     | ε <sub>2</sub> 7  | 5043   | 1·96  | Mn <sub>2</sub> O <sub>3</sub> |   |
|     | ε <sub>3</sub> 2  | 5002   | 0·0   | Mn <sub>2</sub> O <sub>3</sub> |   |

The Bessemer spectrum can conveniently be divided into five groups, α, β, γ, δ, ε. The group α refers to the red field on the less refrangible side of the sodium lines. In this group the Långshytte spectrum has, in addition to the distinct Li line 6707, only three lines or narrow bands that appear on a light continuous background. This continuous background, on which the whole spectrum appears, extends towards the violet side as far as the eye can see (H), and towards the red side with a gradually fading brightness, so that the Li line appears on a dark ground.

The double Na line 5893 appears with a dazzling brightness, and almost darkens the adjacent parts of the field. When the spectrum has gained its full development, the Na group often appears as a broad bright band divided by a reversed line. On the right side of the Na line three groups appear, β, γ, δ, that are sharply defined by the green bands β<sub>1</sub>, γ<sub>1</sub>, and δ<sub>1</sub>. These have such effulgence that the adjacent parts or the continuous background towards the violet are made to appear as if there were absorption-bands at these places.

In the group β, β<sub>1</sub>, and β<sub>2</sub> are bands, the brightness of which decreases towards the red side, and of which β<sub>1</sub> is the brightest. Commonly even β<sub>3</sub> appears as a rather distinct narrow band. Once

there were observed two other faint lines. The group  $\gamma$  consists of three bright bands that fade away towards the red. In the group  $\delta$  there are four equally bright bands that seem to fade towards either side; the shade behind this group is not so distinct as behind the groups  $\beta$  and  $\gamma$ .

The other bands of the spectrum, forming the group  $\epsilon$ , do not appear so distinctly. Usually  $\epsilon_1$  and  $\epsilon_2$  appear, but it is very difficult to determine with accuracy their positions, on account of their short duration and their want of brilliancy. I have not been able to put down the position of  $\epsilon_3$  more than twice and it has been impossible to discover the lines and bands in the violet part of the spectrum.

After the disappearance of the blue flame, there were only the Na and Li lines visible and the bands  $\beta$  and  $\gamma$  of this spectrum. A minute after the beginning of the "boil,"  $\beta$  and  $\gamma$  appeared, and also traces of  $\delta$ , and a minute afterwards the spectrum was fully developed. Lastly appeared the bands of the group  $\epsilon$ , and these were the first to disappear when the proportion of carbon was 1.1 and 1.2 per cent. Then  $\delta_3$  disappeared before the other lines of the group when the carbon was about 0.70 per cent., and generally all the groups  $\delta$  had vanished when the carbon had passed down to 0.40 and 0.35 per cent.

On warming the converter before the "blow" there appear generally, here as elsewhere,\* the principal  $\text{Mn}_2\text{O}_3$  bands ( $\beta_1$ ,  $\gamma_1$ ,  $\gamma_2$ ,  $\gamma_3$ , and  $\delta$ ) and also the Na and Li lines, but on the other hand, when the furnace had been relined, there appeared only the Na and Li lines. If the instrument is directed towards the flame which arises from the flow when the finished Bessemer metal is tapped from the converter, one may perceive a Bessemer spectrum which is almost brighter, and more distinct than during the previous "blow." The group  $\epsilon$  has several bands and appears very distinctly along with other groups, and this is the case even when the "blow" has continued so long that several bands have disappeared before the converter is turned down.

At these works the Bessemer pig-iron contained—

|      |                               |
|------|-------------------------------|
| 1.80 | per cent. of combined carbon, |
| 2.49 | „ graphite,                   |
| 0.91 | „ silicon, and                |
| 2.32 | „ manganese.                  |

#### *The Domnarf Spectrum.*

I have only once observed the Bessemer spectrum at these works, and have no accurate measurements recorded. It differs but slightly,

\* 'Wien Ber.,' vol. 56, p. 26.

however, from the Långshytte spectrum. The line 6252 in the group  $\alpha$  was not present; the two faint lines in the group  $\beta$  and the group  $\epsilon$  appeared very indistinctly, and no new lines or bands were perceived.

*The Nykroppa Spectrum.* (Fig. 1, spectrum II.)

The wave-lengths of the lines and bands are given in the following table. They are arranged in the same manner as in that of the Långshytte spectrum.

This spectrum has a different aspect in the region of red rays from that of the Långshytte spectrum, which, as I have mentioned already, only consists of three red lines on a bright background. Here the group  $\alpha$  consists of a faint continuous spectrum which extends from the Li line, and gradually becomes more conspicuous and splendid towards the more refrangible rays. The band 6255—6211 is defined on the less refrangible edge by this continuous spectrum, and on the more refrangible by a dark background extending to 6028 on which appear the line 6174 and the band 6106—6079. I cannot state positively whether these bands are really bright bands or if they only form part of the continuous spectrum, and are flanked by absorption bands, especially as the brightness of these bands is not greater than that of the continuous spectrum before the "boil."

From 6028 the splendour of the background gradually becomes more intense towards the Na line. On that background there appear sometimes the lines 5972 and 5023. They are, however, of short duration.

The group  $\beta$  shows this difference, that the continuous spectrum extends behind  $\beta_2$  to 5568 before we notice the dark shade which is its usual termination. In addition, some lines appear that were not observed at Långshyttan.

$\gamma$  and  $\delta$  contain respectively each one line on the dark background near the preceding group, which lines were not observed at Långshyttan. The group  $\epsilon$  seems sometimes to be only a bright nebosity, but gradually there appear four very distinct bands.

The order in which the different bands appeared could here be better observed than at Långshyttan, where the spectrum of the blue flame passed into the ordinary Bessemer spectrum. Just when the "boil" begins, a faint yellow line appears very distinctly on the bright continuous background.  $\text{Na}_\alpha$  (5895), and then the second (5889) of the Na lines, and at the same time the  $\text{Li}_\alpha$  line, then almost simultaneously the red band of the group  $\alpha$  and the green ones  $\beta_1$ ,  $\gamma_1$ ,  $\delta_1$ , which remain during the whole "blow." Lastly appear the lines 5972 and 5923 and the bands of the group  $\epsilon$ , these are also the first to disappear. The disappearance of the bands is generally contrary to the order of their appearance.

|                            | <i>n.</i> | $\lambda$ . | $\pm \Delta$ . |                                | Notes.   |
|----------------------------|-----------|-------------|----------------|--------------------------------|--|
|                            | 1         | 6946        | —              | K                              | Once observed only.  |
|                            | —         | 6705        | —              | Li                             | Sharp, red line, always visible.   |
|                            | 1         | 6690        | —              | —                              | Faint line, sometimes visible.   |
| <i>a</i>                   | 10        | 6255        | 2·7            | Mn <sub>2</sub> O <sub>3</sub> | } Broad, red band, not degraded.   |
|                            | 9         | 6211        | 2·95           | CaO                            |  |
|                            | 9         | 6174        | 1·84           | Mn <sub>2</sub> O <sub>3</sub> | Red line, bordered by absorption bands.  |
|                            | 6         | 6106        | 2·9            | —                              | } Red band on a dark background, or possibly the continuous spectrum bordered by absorption bands. |
|                            | 7         | 6079        | 1·5            | —                              |  |
|                            | 2         | 6028        | 1·35           | —                              | Edge of a dark band.   |
|                            | 5         | 5972        | 3·4            | —                              | } Bright line } late in appearing and soon disappearing.   |
|                            | 4         | 5923        | 1·9            | Mn <sub>2</sub> O <sub>3</sub> |  |
|                            | —         | 5895        | —              | Na                             | „ „  |
|                            | —         | 5889        | —              | Na                             | „ „  |
| <i><math>\beta</math></i>  | 5         | 5832        | 1·4            | K                              | } Three yellow lines on a dark background, not always seen.  |
|                            | 6         | 5797        | 1·46           | K                              |  |
|                            | 4         | 5774        | 2·7            | K                              |  |
|                            | 1         | 5746        | —              | —                              | Yellow faint line, once observed.  |
|                            | 5         | 5712        | 1·24           | Mg                             | Yellow line.   |
|                            | 2         | 5629        | 0·7            | K                              | Rarely seen.   |
|                            | 5         | 5609        | 2·1            | Mn <sub>2</sub> O <sub>3</sub> | Green line, always seen.   |
|                            | 6         | 5585        | 1·4            | Mn <sub>2</sub> O <sub>3</sub> | Sharp green band, maximum of light of the group.   |
|                            | 5         | 5568        | 2·2            | —                              | The end of the group.  |
|                            | 5         | 5532        | 2·4            | CaO or BaO                     | } Green band on a dark background.   |
| <i><math>\gamma</math></i> | 5         | 5421        | 2·3            | Mn <sub>2</sub> O <sub>3</sub> |  |
|                            | 3         | 5393        | 0·9            | Mn <sub>2</sub> O <sub>3</sub> |  |
|                            | 4         | 5392        | 0·5            | Mn <sub>2</sub> O <sub>3</sub> |  |
|                            | 6         | 5349        | 0·8            | Mn <sub>2</sub> O <sub>3</sub> |  |
|                            | 1         | 5338        | —              | K                              | Once visible; faint line.  |
| <i><math>\delta</math></i> | 4         | 5318        | 0·95           | K                              | } Green line on a dark background.   |
|                            | 4         | 5267        | 1·4            | Mn <sub>2</sub> O <sub>3</sub> |  |
|                            | 4         | 5226        | 1·4            | Mn <sub>2</sub> O <sub>3</sub> | } Four bands, equally bright and distinctly appearing.   |
|                            | 4         | 5190        | 0·8            | Mn <sub>2</sub> O <sub>3</sub> |  |
|                            | 5         | 5153        | 1·5            | Mn <sub>2</sub> O <sub>3</sub> |  |
|                            | 3         | 5135        | 5·9            | —                              | Rarely seen.   |
|                            | 5         | 5099        | 2·7            | Mn <sub>2</sub> O <sub>3</sub> | Double line, always appearing.   |
|                            | 6         | 5056        | 1·5            | Mn <sub>2</sub> O <sub>3</sub> | Band, always appearing.  |
|                            | 5         | 5018        | 1·3            | Mn <sub>2</sub> O <sub>3</sub> | Band, generally visible.   |
|                            | 5         | 4977        | 1·2            | Mn <sub>2</sub> O <sub>3</sub> | „ „ rarely visible.”   |
|                            | 2         | 4936        | 1·06           | Mn <sub>2</sub> O <sub>3</sub> | „ „ rarely visible.”   |

During the warming of the converter, which generally takes a longer time than at Långshyttan, there first appeared only a faint continuous spectrum, then the Na and Li lines. Next came the most important bands of the groups  $\beta$ ,  $\gamma$ , and  $\delta$ . The red region of the spectrum appeared as a dark band, shading away from 6632

towards 6350. Sometimes a line or faint band appeared at 6106. When the converter was hot the appearance of the group varied incessantly, now being that of a bright band from 5585 to 5718, shading away towards the red, now being a much narrower one from 5585 to 5608. The broad band often divides for a moment into two, an absorption line 5625 flashing out alternately with what appears to be an absorption band 5648—5600. If the converter was not so hot,  $\beta_1$  only was visible as usual,  $\gamma_1$  was always visible, and sometimes also  $\gamma_2$ . Of the group  $\delta$  there was nothing seen but the brilliant edge 5153.

The Nykroppa Bessemer pig-iron generally contained—

|       |                               |
|-------|-------------------------------|
| 0.70  | per cent. of combined carbon, |
| 4.07  | „ graphite,                   |
| 0.75  | „ silicon,                    |
| 1.36  | „ manganese,                  |
| 0.015 | „ phosphorus,                 |
|       | and traces of sulphur.        |

Two samples of this pig-iron were examined for manganese; the first on one occasion when the group  $\epsilon$  had appeared very faintly, and the other one when four bands of the group  $\epsilon$  had been distinctly visible. The result was that the former sample contained a little more manganese than the latter, which proves that the changes in the proportion of manganese have no effect upon the more or less distinct appearance of the group  $\epsilon$ .

### *The Hagfors Spectrum.*

This spectrum differs from the former only in some small details. The group  $\alpha$  consists here of a broad bright band with distinct limits  $\lambda = 6277$  and  $\lambda = 6179$ . This band has on the side of less refrangible rays the continuous background of rays, but on the more refrangible side of 6179 it has, as it seems, an absorption band, which extends to the narrow and bright band 6106 ( $\text{Li}\beta$ ) and then the bright background adjoins it again. In the group  $\beta$  there is a new line visible 5860 ( $\text{Mn}_2\text{O}_3$ ), and the band 5712 appears more distinctly limited already at 5585. The Nykroppa and Hagfors spectra fully agreed, except in the following details, namely, the group  $\epsilon$  of the latter spectrum was more often indistinct, and that it never exhibited so many bands as the former.

When the converter was being warmed there appeared certain bands, which were not visible during the “blow,” viz., a faint narrow band with  $\lambda = 5923$ , and a distinct one with  $\lambda = 5525$ —5491 (5525 being the most brilliant edge), not, however, quite so brilliant as  $\beta_1$ .



In addition there appeared the Li and Na lines, the bands 6277—6179,  $\beta_1$  and  $\gamma_1$ .

The pig-iron contained—

|           |                        |
|-----------|------------------------|
| 0.89—0.98 | per cent. of silicon,  |
| 1.78—2.14 | „ manganese,           |
| 0.025     | „ phosphorus,          |
|           | and traces of sulphur. |

#### SPECTRA FOR COMPARISON.

##### *The Manganese Oxide Spectrum.*

Simmler proved that compounds of manganese heated in a Bunsen flame give a band spectrum. Lichtenfels and Watts gave evidence of the Bessemer spectrum being for the most part derived from manganese oxide. In order to ascertain which lines were to be attributed to  $Mn_2O_3$ , I examined the spectrum of manganese oxide belonging to the department of physics in the University of Upsala. Following the method of Watts, I used pure manganese chloride on a platinum wire in the oxyhydrogen flame. The spectrum observed agreed very well with the spectrum described by Watts and Lecoq.\* But Lecoq has described three manganese oxide spectra, obtained by passing the electric spark of an induction coil from a platinum electrode through a solution of pure manganese chloride, which formed the negative pole.

The spectrum obtained with the short spark is a compound one, consisting of both lines and bands. The line spectrum, however, is more developed and agrees more closely with Thalén's manganese spectrum. He also obtained the same spectrum by making use of a moderate sized spark nearest to the negative pole, but at a short distance from the surface of the fluid it gradually passed into the spectrum the position of the lines of which are given in the table of wave-lengths. It contains both lines and bands. Some of the lines are absent, and several new bands have appeared. Lecoq's third manganese-oxide spectrum may be observed when manganous chloride is heated in a Bunsen flame. It consists of the most important bands of the last-mentioned spectrum.

Watts, in his table of the  $Mn_2O_3$  spectrum, has given the positions of only the bands and lines which fully agree with his Bessemer and Spiegel iron spectra. It is, therefore, only natural that I should have observed by means of the same method a greater number of lines in the green region of the spectrum.

\* 'Spectres Lumineux,' par Lecoq de Boisbaudran, Paris, 1874, p. 110.

*The Bessemer Spectrum as observed at Långshyttan.*

| $\lambda$ |   |              |   |
|-----------|---|--------------|---|
| 6252      | } | $\alpha_3$   | To ascertain the origin of this spectrum<br>it was compared with that obtained<br>from manganese compounds, from<br>which the following measurements<br>were taken:—6252, 6202, 6187, 6148,<br>5888, 5859, 5808, 5757, 5710, 5672,<br>5610, 5581, 5425, 5388, 5359, 5267,<br>5228, 5193, 5151, 5129, 5092, 5048,<br>5004, 4969, 4921, 4820. |
| 6208      |   | $\alpha_2$   |   |
| 6176      |   | $\alpha_1$   |   |
| 5855      | } | $\beta_3$    |   |
| 5608      |   | $\beta_2$    |   |
| 5581      |   | $\beta_1$    |   |
| 5426      | } | $\gamma_3$   |   |
| 5389—87   |   | $\gamma_2$   |   |
| 5353      |   | $\gamma_1$   |   |
| 5264      | } | $\delta_4$   |   |
| 5227      |   | $\delta_3$   |   |
| 5189      |   | $\delta_2$   |   |
| 5160      | } | $\delta_1$   |   |
| 5103      |   | $\epsilon_1$ |   |
| 5043      |   | $\epsilon_2$ |   |
| 5002      |   | $\epsilon_3$ |   |

The most distinctly defined edge of each band was measured, and this lay on the side towards the violet.

The band  $\gamma_3 = 5264$  of my Långshytte spectrum occurs in all the spectra of Lecoq. I have found it not only in the spectrum mentioned above, produced by means of the flame of detonating gas, but also in a manganese oxide spectrum, which was obtained at the mining school at Filipstad by passing pure manganese chloride into the flame of a gasoline lamp. It is surprising that Watts has not pointed out this band, or found that it agrees with the line 5269 in his Bessemer spectrum.

It is true that this band, by comparison with other bands of the  $\delta$  group, seems a little fainter in the  $Mn_2O_3$  spectrum than in the Bessemer spectrum, and that one may therefore suppose that some line of another element is present in the same place, but I am not able to agree with Watts in assigning this line to iron, on account of the few concordant iron lines.

$\alpha_3$  ( $\lambda = 6252$ ) fully agrees with my  $Mn_2O_3$  spectrum, and with that of Lecoq, but not with that of Watts.

But, on the other hand, there is in the Långshytte spectrum a narrow line (6176) which corresponds to 6178 in Watts'  $Mn_2O_3$  spectrum, but which does not agree with the bands observed by Lecoq and myself. It is, however, very difficult to decide how the matter really stands, but most likely it is owing to the well-known fact that  $Mn_2O_3$  changes its aspect according to conditions of temperature under which it is produced, several bands which are visible at first fade away, while others which at first are obscure grow more

and more distinct.  $e_3$  ( $\lambda = 5002$ ) is also most probably due to  $Mn_2O_3$ , as also the other bands of the  $\epsilon$ -groups of both the Långshytte spectrum and that of Nykroppa. The band 5226 might also be considered to be derived from the same source.

*Note.*—Since the publication of Professor Hartley's two papers on "The Spectrum of Metallic Manganese, of Alloys of Manganese, and of Compounds containing that Element," and on "The Spectroscopic Phenomena and Thermo-Chemistry of the Bessemer Process," 'Phil. Trans.,' vol. 185, A, p. 1029, I have become aware that the bands originally attributed by Watts to manganese oxide, and which I have described as  $Mn_2O_3$ , are now for the most part to be ascribed to metallic manganese.—July 4, 1895.—C. J. L.

### *The Phosphorus Spectrum.*

Phosphorus is known to yield a spectrum, the most brilliant band of which has the same position as  $e_1$ , and this may serve as an explanation of the fact that  $e_1$  appears much more distinctly in the Bessemer spectrum than in the  $Mn_2O_3$  spectrum. Salet\* and Lecoq† have given descriptions and measurements of this spectrum. I observed it in the Physical Laboratory at the University of Upsala. A current of hydrogen was passed over a piece of yellow phosphorus, and through a long glass tube into the air where the hydrogen was burnt. To cool the flame, after the manner of Salet, it was surrounded by a current of cool air. The flame thereby appeared green, and gave in the spectroscopie the band spectrum of phosphorus. The bands of the spectrum varied in breadth, so that I obtained an almost continuous spectrum with a large piece of phosphorus, while a smaller piece gave bands that shaded away gradually as the piece of phosphorus wasted away. By using a piece of phosphorus so proportioned that the most important bands were as narrow as possible, so as to be distinctly observed, I made a series of measurements in such a manner that only the maximum of light in each band was recorded. As, however, these bands shade away both towards the least and the most refrangible rays, the numbers quoted cannot be very exact.

In the following table I give the values of  $\lambda$  obtained by Salet, Lecoq, and myself; the figures refer to the maximum of light of the strongest bands, and, in addition, I give the bands of the Bessemer spectrum agreeing with them.

\* 'Annales de Chimie et de Physique,' vol. 4, No. 28, p. 57.

† 'Spectres Lumineux,' par Lecoq de Boisbaudran, p. 187.

| Phosphorus Spectrum. |        |          | Bessemer spectrum of Långshyttan. |
|----------------------|--------|----------|-----------------------------------|
| Salet.               | Lecoq. | C. J. L. |                                   |
| $\gamma$ . 559       | 5605   | 5590     | 5581—5608                         |
| $\alpha$ . 525       | 5263   | 5255     | 5264                              |
| $\beta$ . 511        | 5106   | 5110     | 5103                              |

$\alpha$  is the brightest, then  $\beta$ , and lastly  $\gamma$ .

By this, one can see that  $\alpha$  agrees well with  $\delta_4$  in the Bessemer spectrum.  $\beta$  and  $\gamma$  in the phosphorus spectrum are to be found almost at the same place as  $\epsilon_1$  and  $\beta_1$  in the  $\text{Mn}_2\text{O}_3$  spectra, and they may, therefore, form part of the Bessemer spectrum, but it must be remarked that there has not been noticed any greater brightness in these bands  $\epsilon_1$  and  $\beta_1$  in the Bessemer spectrum, than in the  $\text{Mn}_2\text{O}_3$  spectrum. The presumption that phosphorus should contribute to the Bessemer spectrum is incompatible with the fact that Bessemer metal generally contains a higher percentage of phosphorus than the pig-iron from which it is made, which circumstance has led metallurgists to suppose that all the phosphorus of the pig-iron remains in the final product. Analyses of the iron and slag made during different periods of a "blow" prove, however, that the proportion of phosphorus varies, so that one may be justified in supposing that phosphorus may contribute to the heat of oxidation.

Analyses made by Kessler give the following proportions of phosphorus in the metal:—

| Pig-iron.    | Samples taken during "blow." |       |       |                 |
|--------------|------------------------------|-------|-------|-----------------|
|              | I.                           | II.   | III.  | IV.             |
| Phosphorus.. | 0.100                        | 0.106 | 0.096 | 0.097           |
|              |                              |       |       | 0.109 per cent. |

and Kupelwieser gives analyses of slags where—

- I. Forge-slag;
- II. Slag at the beginning of the "boil";
- III. Slag at the end of the "boil"; and
- IV. Slag at the end of the "blow," give the following per cent. of phosphorus:—

| I.   | II.  | III. | IV.  |
|------|------|------|------|
| 0.01 | 0.03 | 0.02 | 0.01 |

Kupelwieser has also calculated the absolute quantities of the elements of a charge, and has found phosphorus, 1.47 kgr., in the pig-iron, and 1.34 kgr., in the final product, of which there consequently remains 0.13 kgr., which has partly passed into the slag and partly through the mouth of the converter.

That under such circumstances the trace of phosphorus required to give the spectrum of this element volatilises, even under conditions

where the percentage of phosphorus in the metal is small, ought not then to be considered as too bold a presumption.

### *The Lithium Spectrum.*

$\text{Li}\alpha$  ( $\lambda = 6705$ ) is found in every spectrum. Besides  $\text{Li}\beta$  ( $\lambda = 6102$  according to Thalén,  $\lambda = 6098$  according to Huggins\*) may be considered as agreeing with the sharp line 6097 in Watts' Bessemer spectrum, and the band 6106 in Hagfors spectrum, and possibly it may form part of the band 6106—6079 in the Nykroppa spectrum.

### *The Potassium Spectrum.*

A spectrum produced by means of a potassium salt in the electric spark gives a line spectrum, which, according to the measurements made by Lecoq, chiefly consists of the groups  $\alpha$ , with  $\lambda = 5831$ —5801—5783,  $\beta$  with  $\lambda = 5355$ —5336—5319 and,  $\gamma$  with  $\lambda = 6946$ —6913. At Nykroppa  $\gamma$  has been observed at least once. It may, therefore, be admitted as something quite certain that the groups in the Nykroppa and Hagfors spectra, 5832—5797—5774 and 5338—5318, are derived from potassium, and likewise possibly the lines 5823 and 5781 in the Långshytte spectrum.

### *The Calcium Oxide Spectrum.*

Of this spectrum Lecoq has fine drawings and careful measurements. The most important bands are  $\alpha$  with  $\lambda = 6265$ —6202—6181,  $\beta$  with  $\lambda = 5543$ —5517, and  $\gamma$  with  $\lambda = 5933$ .

With traces of  $\text{CaO}$  on a platinum wire, heated in a Bunsen flame, there will appear only the two first bands faintly, and of these  $\beta$  remains longest. I heated  $\text{MnCl}_2$ , together with traces of  $\text{CaCl}_2$ , on a platinum wire in a gasoline lamp, and then observed the red band 6277—6179, and faintly the band 5532, as well also the  $\text{Mn}_2\text{O}_3$  spectrum which was observed in the Hagfors spectrum. Likewise, I obtained with a larger quantity of  $\text{CaCl}_2$ , and a smaller proportion of  $\text{MnCl}_2$ , quite that spectrum which appeared before the "blow" at Hagfors, and in which  $\text{CaO}\beta$  appears distinctly, and  $\text{CaO}\gamma$  appears faintly; the band 5532, and the appearance of the band 6255—6211 in the Nykroppa spectrum might also be due to traces of  $\text{CaO}$ .

### *The Magnesium Spectrum.*

Another explanation of the band 5532 in the Nykroppa and Hagfors spectra, which also should explain the line 5712, is given by

\* See Kayser, 'Lehrbuch der Spectralanalyse,' p. 290.

the spectrum of magnesium. According to Liveing and Dewar,\* Mg gives in the arc the following values for  $\lambda$ : 5711, 5528, **5183, 5172, 5167**, 4704. The line 5711 appears brightly, and generally very distinctly, just when a little piece of magnesium has been placed in the arc; it then rapidly diminishes, and by degrees becomes very faint, or completely disappears. The same line appears also in the spark when taken from a solution of  $\text{MgCl}_2$ . In the spark all lines mentioned above are to be found. The groups 5183—5172—5167 that correspond to  $b$  in the sun spectrum appear, however, comparatively fainter than in the arc,† on account of which one might conclude that with another temperature and another pressure the lines 5710 and 5529 would remain longest, that is to say, that these would differ from the  $b$  lines, and by this one might also explain the reason why 5712 appears more distinctly in the Hagfors spectrum than in the Nykroppa spectrum.

#### *The Magnesium Oxide Spectrum.*

Magnesium oxide has the sharpest edge of its brightest band at 5006,‡ and corresponds better with the faint band 5002 in the Långshytte spectrum than with the  $\text{Mn}_2\text{O}_3$  band, to which also its origin might be attributed.

#### *The Barium Oxide Spectrum.*

This spectrum has a band with  $\lambda = 5536$ , which may account for he line 5532 in the Nykroppa spectrum.

## II.

#### *The Spectrum of the Blue Flame.* (Fig. 1, spectrum IV.)

This spectrum was visible only for a few seconds during each “blow,” and was consequently difficult to deal with. Often when it appeared the instrument was not properly adjusted, or, owing to parallax, no reliable values could be obtained for the position of the lines. The spectrum being of so short a duration, there was no time to write down more than one or two lines during a “blow.” It seems, however, to be of interest in more than one respect, and on this account I have examined the spectrum as well as circumstances allowed, only making one or two observations of the faintest and most rarely appearing of the twenty-eight bands and lines that are visible. In the following table the results of these observations are given.

\* ‘Roy. Soc. Proc.,’ vol. 30, p. 97.

† See Capron, ‘Photographed Spectra,’ London, 1877, Plate XI.

‡ Lecoq, ‘Spectres Lumineux,’ p. 86.

|              | <i>n.</i> | $\lambda$ . | $\pm \Delta$ . |  | Notes.  |
|--------------|-----------|-------------|----------------|--|---|
| $\alpha$ {   | —         | 6705        | —              | Li                                     |   |
|              | 1         | 6208        | —              | Mn <sub>2</sub> O <sub>3</sub>         | Faint line.   |
|              | 1         | 6176        | —              | Mn <sub>2</sub> O <sub>3</sub>         | " "   |
|              | —         | { 5895 }    | —              | Na                                     |   |
|              | —         | { 5889 }    | —              | Na                                     |   |
| $\beta$ {    | 2         | 5709        | 0·7            | —                                      | Fine line.  |
|              | 4         | 5678        | 1·36           | Si                                     | Strong bright band, with some shading towards the red.  |
|              | 8         | 5581        | —              | Mn <sub>2</sub> O <sub>3</sub>         | Strong bright band, shading away to the red.  |
| $\gamma$ {   | 6         | 5451        | 1·6            | Si                                     | } Strong bright band, with some shading towards the red.<br>} Fainter bright band.<br>} Strong bright band, shading away towards the red.   |
|              | 3         | 5387        | —              | Mn <sub>2</sub> O <sub>3</sub>         |   |
|              | 10        | 5353        | —              | Mn <sub>2</sub> O <sub>3</sub>         |   |
| $\delta$ {   | 1         | 5339        | —              | —                                      | } Faint line.<br>} Like the group $\delta$ in the Bessemer spectrum. Here 5227 is strongest.  |
|              | 6         | 5264        | —              | Si                                     |   |
|              | 7         | 5227        | —              | { Mn <sub>2</sub> O <sub>3</sub><br>Si |   |
|              | 7         | 5189        | —              | Mn <sub>2</sub> O <sub>3</sub>         |   |
|              | 8         | 5160        | —              | Mn <sub>2</sub> O <sub>3</sub>         |   |
|              | 2         | 5085        | 1·34           | Mn <sub>2</sub> O <sub>3</sub>         |   |
| $\epsilon$ { | 4         | 5043        | —              | Mn <sub>2</sub> O <sub>3</sub>         | } Faint band.<br>} Distinctly appearing band.<br>} " " "  |
|              | 3         | 5008        | 0·7            | { Mn <sub>2</sub> O <sub>3</sub><br>Si |   |
|              | 10        | 4986        | 1·06           | —                                      |   |
|              | 7         | 4963        | 2·26           | Mn <sub>2</sub> O <sub>3</sub>         |   |
| $\eta$ {     | 1         | 4871        | —              | Si                                     | } Strong band.<br>} Faint band.<br>} " "<br>} Strong line or narrow band.<br>} Fainter band.<br>} Stronger band.<br>} Fainter band.<br>} Rarely visible bands, difficult to define. |
|              | 1         | 4854        | —              | —                                      |   |
|              | 4         | 4809        | 0·85           | Si                                     |   |
|              | 2         | 4748        | 3·4            | Si                                     |   |
|              | 6         | 4655        | 1·34           | Si                                     |   |
|              | 2         | 4540        | 1·35           | —                                      |   |
|              | 1         | 4492        | —              | —                                      |   |
|              | 1         | 4394        | —              | —                                      |   |

In the group  $\alpha$  the lines belonging to Mn<sub>2</sub>O<sub>3</sub> found in the Bessemer spectrum have appeared only once. Li <sub>$\alpha$</sub>  and Na <sub>$\alpha$</sub>  double line always appear, on the contrary, very distinctly. Besides many other bands which are observed in the Bessemer spectrum, viz.,  $\beta_1$ ,  $\gamma_1$ , and  $\gamma_2$ , there are the groups  $\delta$  and  $\epsilon_1$  and  $\epsilon_2$ . In addition, the spectrum of the blue flame contains some bands that are so strong that the appearance of the spectrum essentially differs from that of the Bessemer spectrum.

All these bands shade off towards the red. The bands 5678 of the group  $\beta$ , and 5451 of the group  $\gamma$ , have a width and brightness comparable to those of the band 5581;  $\delta_3$  and  $\epsilon_3$  appear more distinctly than in the Bessemer spectrum, and in addition there are six rather bright bands in the blue-violet part.

The *blue flame* did not make its appearance equally soon in the different "blows." Sometimes it appeared immediately at the begin-

ning of the "blow," sometimes only after a while, and then the spectrum was continuous. In the former case the "boil" was hotter than in the latter. Experience has shown that the *blue flame* appears earlier when the pig-iron is strong in silicon, independently of the charge being cold or hot. And if the treatment is basic, the *blue flame* will appear sooner than if it is acid, other conditions being the same.

### *Comparison Spectra.*

That several of the bands that are to be found in the spectrum of the *blue flame* agree with the Bessemer spectrum is evident, and likewise that these are owing to manganese oxide. From the fact that the more refrangible rays relatively grow in brightness as the temperature becomes higher,\* one might suppose that the bands of the group  $\epsilon$  with  $\lambda = 4986$  and  $\lambda = 4963$ , and possibly even other bands, are owing to manganese oxide. The spectrum which, other than that of manganese oxide, agrees best with that of the *blue flame* is that of silicon.

### *The Silicon Spectrum.*

Salet† obtained a band spectrum by passing hydrogen over silicon chloride, and surrounding the hydrogen flame with an air current in the same manner as in the production of the phosphorus spectrum mentioned above. I have been unable to decide whether it is owing to elementary silicon or to any of its compounds. I have tried to produce this spectrum by Salet's method, but without success.

The wave-lengths of the middle of the bands, thus observed by Salet, approximate closely to the most important bands which occur in the spectrum of the *blue flame*, viz.,  $\alpha$  522,  $\beta$  545,  $\gamma$  501,  $\delta$  567, and  $\epsilon$  487.5 (though faintly),  $\text{Si}_d$  ( $\lambda = 522$ ) agrees as to its position with the  $\text{Mn}_2\text{O}_3$  band  $\delta_3$  ( $\lambda = 5227$ ); that in the *blue flame* appears with greater brightness than the other bands of the  $\delta$  group.

In addition to these complete agreement is also to be found between the bands 481 and 474 in the Si-spectrum and those of the *blue flame* 4809 and 4778, though it must be remarked that the band corresponding to  $\text{Si}_e$  is fainter than those of the *blue flame*.

There are other reasons, too, for the fact that silicon, or one of its compounds, gives a spectrum where the *blue flame* appears. During the slag-period really nothing takes place but an oxidation of Si and Mn, which process of combustion occasions a considerable increase of the temperature. These elements having passed completely into the slag, the carbon begins to burn, and then the second period,

\* 'Spectres Lumineux,' par Lecoq de Boisbaudran, p. 43.

† 'Annales de Chimie et de Physique,' vol. 4, No. 28, 1873, p. 66.



the "boil," ensues. It is possible that at the transition between these periods, the temperature may be higher than at any other time during the "boil," and part of the silicon may be vaporised and thus give this spectrum.

It would be reasonable to suppose that this spectrum should be chiefly owing to carbon or one of its compounds, but I have found no agreement between this spectrum and those attributed to carbon. The origin of the other bands and lines of the spectrum of the *blue flame* I have not been able to find out. Sodium shows a certain agreement with the Na-lines (according to Thalén\*), 5687—5681, 5155—5153, and 4983, corresponding to 5678, 5160, and 4986, but against this presumption there stands the fact that  $\text{Na}\beta$  6160—6154 does not occur.

Though agreement as to position with some of the lines of other elements may be found, yet one cannot, upon the whole, determine the origin of this spectrum.

### III.

#### *The Ulfshytte Spectrum.* (Fig. 1, spectrum III.)

Having ascertained that in all probability silicon forms part of the spectrum of the *blue flame*, and on being informed that at Ulfshyttan the pig-iron used contains much silicon and little manganese, I thought it would be interesting to examine the Bessemer flame by means of the spectroscopie.

According to the information given me by engineer Carl Carlsson concerning the Bessemer process at Ulfshyttan, I am able to communicate the following facts concerning the composition of the metal :—

|  | Carbon,<br>per cent. | Silicon,<br>per cent. |
|--|----------------------|-----------------------|
| 1. The pig-iron from the blast-furnace contains                                  | 4.0                  | 2.0                   |
| 2. The metal in the converter at the beginning<br>of the <i>blue flame</i> ..... | 4.20                 | 0.7                   |
| 3. The finished Bessemer-iron.....   | 0.05                 | traces of<br>0.02     |

The percentage of manganese in the pig-iron is 0.10 per cent. —0.15 per cent., and in some degree this diminishes during the "blow," but it can hardly be oxidised even by iron fully "blown," more than to about 0.05 per cent. Of sulphur both the pig-iron and the final product contain 0.02 per cent. or less, and of phosphorus respectively 0.06 per cent. and 0.03 per cent. The *blue flame*

\* "Mémoire sur la détermination des longueurs d'onde des raies métalliques."  
'Nova Acta Regiæ Societ. Scient. Upsaliensis,' 1868.

appears very intense and constant with a very hot charge, and then the proportion of silicon is about 1 per cent. at its appearance. The last tenths per cent. of the silicon are not oxidised until all the carbon is burnt, the final product receiving a very high temperature. Here the charge is thought to be too hot. With a normal charge the proportion of carbon begins to decrease upon the appearance of the *blue flame*, but as long as this is visible ( $\frac{1}{2}$  to  $1\frac{1}{2}$  minutes) the silicon decreases more rapidly and when the flame has become white, one may be quite certain that there is no large percentage of silicon left in the bath. The "blow" lasts about 15 minutes. With extra cold charges the *blue flame* appears almost immediately after the erection of the converter and it becomes white very soon.

I did not, however, succeed in observing a spectrum of the *blue flame* under these conditions. During my stay at Ulfshyttan the charge was never too hot but was always normal, and the *blue flame* appeared to the naked-eye more milky than at Långshyttan, but it did not give any distinguishing spectrum. A Bessemer spectrum was, however, observed both during the "boil" and during the decarbonisation, and this differed essentially from the Bessemer spectra already described. This is a matter of course, as the silicon here takes the place of the manganese.

Only the most brilliant manganese-oxide bands are to be found in this spectrum. The wave-lengths of the bands and lines appear in the table (p. 94).

This spectrum has quite a different appearance from that of the ordinary Bessemer spectra. In the red field there are two strong bands which are always very distinctly visible. Then there are two lines, one of which ( $\lambda = 6088$ ) seems, however, to coincide with the stronger edge of a faint band shading away towards the left (red) and on which the other line ( $\lambda = 6108$ ) is to be found. The yellowish-green field is chiefly remarkable for two bright bands, which seem to be separated by an absorption band. Between those bands and the sodium line some bright lines and a band are to be found and, in addition, other bands and lines which, however, rarely appear.

To the left of the bands above mentioned there also appear on the back-ground of continuous rays a narrow band and several distinct lines or possible narrow bands.

The order in which the lines appeared was somewhat different in different "blows." The  $\text{Na}_\alpha$ - and  $\text{Li}_\alpha$ -lines invariably appeared first, and then the bands 5611 and 5580. Then on one occasion 5415 and 5377 were observed before the other lines, while at another time 5642 appeared after 5611 and 5580, after which the bands and lines presented themselves in the following order: 5814, 5784, 5867; 5524, 5377, 5258, 5355, 5312, and lastly 5415, 5388, 5159, 5099.

| <i>n.</i> | $\lambda$ . | $\pm \Delta$ . |                                    | Notes.  |
|-----------|-------------|----------------|------------------------------------|---|
| —         | 6705        | —              | Li                                 |   |
| 1         | 6435        | —              | —                                  | Faint.  |
| 10        | 6225        | 2·1            | CaO                                | The right edge of a strong band shading away towards the red. |
| 10        | 6185        | 0·76           | CaO                                | Do. do. do.   |
| 8         | 6108        | 1·6            | Li                                 | Line. Probably lithium.                                       |
| 9         | 6088        | 2·2            | —                                  | Line or possibly narrow band shading away towards the red.    |
| 5         | 6044        | 1·8            | —                                  | Narrow band.  |
| 6         | 6016        | 2·7            | Mn <sub>2</sub> O <sub>3</sub> ?   | Do. Doubtful.   |
| 8         | 5969        | 1·4            | —                                  | Band shading away towards the red.                            |
| 3         | 5914        | 2·2            | —                                  | Fainter.  |
| —         | { 5895 }    | —              | { Na }                             |   |
| —         | { 5889 }    | —              | { Na }                             |   |
| 11        | 5867        | 0·86           | —                                  | Strong line.  |
| 9         | 5814        | 1·1            | —                                  | Band shading away towards the red.                            |
| 1         | 5802        | —              | K                                  | Faint line.   |
| 13        | 5784        | 0·8            | K                                  | Line.   |
| 2         | 5691        | 0·7            | —                                  | Faint band.   |
| 1         | 5678        | —              | Na                                 | Faint line.   |
| 1         | 5667        | —              | Na                                 | Do.   |
| 10        | 5642        | 1·5            | Mn <sub>2</sub> O <sub>3</sub> *   | Band shading away towards the red.                            |
| 17        | { 5625 }    | 0·8            | { Mn <sub>2</sub> O <sub>3</sub> } | Strong band shading away towards the red.                     |
|           | { 5611 }    |                | { P }                              | Strong band, shading away towards the violet,                 |
| 17        | { 5591 }    | 0·7            | { Mn <sub>2</sub> O <sub>3</sub> } |   |
|           | { 5580 }    |                |                                    |   |
| 1         | 5540        | —              | P                                  | Faint line, rarely seen.                                      |
| 2         | 5524        | 3·05           | Mg                                 | Line.   |
| 1         | 5433        | —              | P                                  | Faint, rarely visible.  |
| 6         | 5415        | 1·3            | —                                  | Faint band.   |
| 4         | 5388        | 0·5            | Mn <sub>2</sub> O <sub>3</sub>     | Band.   |
| 4         | 5377        | 1·1            | —                                  | Sharp line, distinctly appearing.                             |
| 6         | 5355        | 1·8            | Mn <sub>2</sub> O <sub>3</sub>     | " " "   |
| 7         | 5312        | 0·55           | —                                  | " " "   |
| 12        | 5258        | 0·6            | P                                  | " " "   |
| 7         | 5159        | 0·66           | Mn <sub>2</sub> O <sub>3</sub>     | Narrow line.  |
| 5         | 5099        | 0·45           | P                                  | Do.   |
| 1         | 4918        | —              | —                                  | Faint line.   |

These disappeared towards the end of the period of decarbonisation, so that those latterly visible were the Na<sub>8</sub>- and Li-lines, and the bands 5784, 5611, and 5580; finally, when the converter was turned down, the metal having 0·10 and 0·15 per cent. of carbon, there were only the Na<sub>8</sub>- and Li-lines left visible.

When the converter was warmed the following bands were seen:—

\* Most probably manganese oxide.

| <i>n.</i> | $\lambda$ .      | $\pm \Delta$ . |          | Notes.   |
|-----------|------------------|----------------|----------|--|
| —         | 6705             | —              | Li       |  |
| 6         | { 6257<br>6225 } | 3.1            | CaO      | { Band with its sharpest edge towards the red.                             |
| —         | { 5895<br>5889 } | —              | Na<br>Na |  |
| 7         | { 5580<br>5569 } | 1.2            | —        | { Sharp band, shading away towards the red.                                |
| 4         | { 5536<br>5518 } | 0.9            | CaO      | { Sharp band, shading away towards the violet.                             |
| 1         | 5417             | —              | —        | Faint line.  |
| 4         | 5374             | 1.3            | —        | { Two strong lines, or possibly narrow bands shading away towards the red. |
| 4         | 5343             | 1.4            | —        |  |

### Comparison Spectra.

The origin of the chief portion in the Ulfshytte spectrum, I have been unable to ascertain. Though several lines and bands of elements that might be supposed to form that spectrum correspond with it to some extent, yet one cannot state positively that there is any connection between these spectra and the Ulfshytte spectrum.\*

Notwithstanding the small percentage of manganese in the metal used at these works there is no doubt that the most important of the manganese-oxide bands are to be found. The most brilliant of them,  $\beta_1$  and  $\beta_2$ , certainly show to some degree an appearance differing from that in the spectra mentioned above, a dark band separating them, and near to  $\beta$ , the Ulfshytte spectrum shades away more to the violet than to the red, but this is only due to a band of another element situated almost in the same place. The fact that two of these  $Mn_2O_3$  bands are marked in the Ulfshytte spectrum as lines, only signifies that they are more sharply defined in this spectrum. I presume this is due to the small proportion of manganese in the metal and to the high temperature of the "blow" at these works.

Presuming that the phosphorus-spectrum, described on page 87, could under favourable circumstances show sharply defined bands so that they more resemble lines situated where the maxima of light of the present bands are to be found, we have a plausible explanation of the lines 5258 and 5099, and possibly of the appearance of the band

\* I have studied the following works especially for this purpose of obtaining an explanation of the spectra herein described, namely: Kayser's 'Spectrum Analysis,' Thalén, 'Mémoire sur la Détermination des Longueurs d'Onde des Raies Métalliques,' Upsal, 1868; Ångström et Thalén, 'Recherches sur les Spectres des Metalloïdes,' Upsal, 1875; Lecoq de Boisbaudran, 'Spectres Lumineux,' Paris, 1874; and Salet, "Spectres des Metalloïdes" ('Annales de Chim. et de Physique,' vol. 4, No. 28, Paris, 1873).

5591—5580 in the Ulfshytte spectrum. Lecoq\* gives fainter bands belonging to this spectrum at 5538 and 5436, which correspond to the lines 5540 and 5433 which were observed on one occasion.

The lines that I have put in the fourth column of the table as being derived from CaO and K agree as with the position of lines in other spectra which have been described as belonging to CaO and K, but cannot with certainty be ascribed to them. In the same manner it is uncertain whether the line with  $\lambda = 6108$  belongs to Li or not.

Finally, it may be remarked that 5642 agrees as to its position with one of the strongest lines in the sulphur spectrum, and that some of the bands in the band spectra of carbon have a certain correspondence, though the strongest bands are missing.

As to the spectrum during the warming of the converter, two bands may be ascribed to CaO, the rest being of unknown origin.

With increased knowledge of these band-spectra, and of the effects of temperature and of pressure upon them, I hope that the mystery which at present surrounds the cause of their appearance in different works during different periods of the "blow" will admit of full explanation.

#### IV.

##### *On the Practical Use of the Spectroscope in the Bessemer "Blow."*

That the spectroscope in most cases puts a sharp mark on the moment of complete decarbonisation was established long ago, but whether it can be used at all with the method we have in Sweden of stopping the "blow" just as the Bessemer metal has so altered in composition as to contain no more than the desired percentage of carbon is more difficult to decide.

At Nykroppa the object was to obtain a percentage of carbon as high as 0·85, at Hagfors as low as 0·15, while at Långshyttan it was required to be 0·65. During a considerable period the changes of the spectrum at the end of every "blow" were observed, and the aspect of the characteristic groups were recorded as carefully as possible just at the moment of the interruption of the "blow."

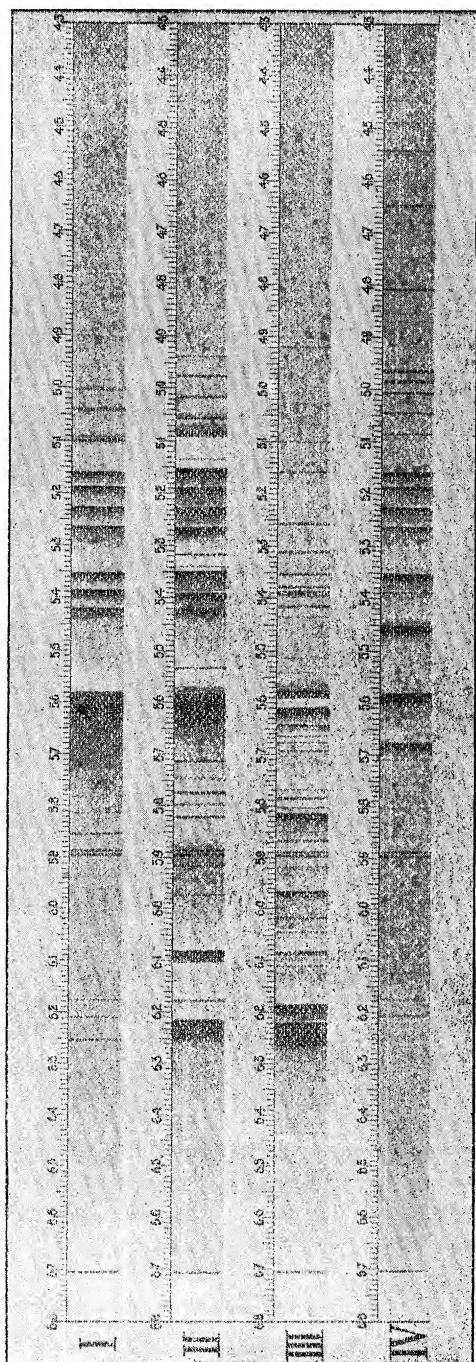
The following table (p. 98) shows the aspect of the spectrum under normal conditions.

By means of these rules I tried to direct the "blow" and get a metal with 0·65 per cent. of carbon. The result of the first twelve "blows" was metal containing 0·70, 0·50, 1·50, 0·65, 0·65, 0·60, 0·65, 0·75, 0·65, 0·60, 0·65, 0·60 per cent. of carbon.

It may be observed here that a group of rays sometimes disappears and soon appears again with diminished brightness. The error in the value of No. 3 was due to uncertainty in observing, but with some practice such an error may easily be avoided.

\* 'Les Spectres Lumineux,' par Lecoq de Boisbaudran, p. 189.

FIG. 1.



- I. Bessemer spectrum from Långshyttan.
- II. " " Nykroppa.
- III. " " Ulfshyttan.
- IV. Spectrum of the blue flame at Långshyttan.

| Per cent.<br>carbon.    | The aspect of the spectrum.  |
|-------------------------|--|
| 1·2 }<br>1·1 }<br>1·0 } | The group $\epsilon$ just disappearing, the group $\delta$ very distinct.      |
| 0·90                    | The group $\delta$ a little fainter.   |
| 0·80                    | " " yet fainter.   |
| 0·75                    | $\delta_3$ and $\delta_4$ fainter than other bands of the group.               |
| 0·70                    | $\delta_3$ and $\delta_4$ indistinct.  |
| 0·60                    | $\delta_3$ just disappeared.   |
| 0·55                    | $\delta_3$ and $\delta_4$ are away.  |
| 0·40                    | The group $\delta$ away.   |
| 0·20                    | The group $\delta_1$ $\gamma_3$ , $\beta_2$ and generally $\gamma_2$ are away. |

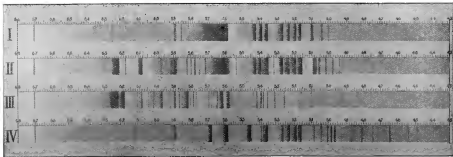
Subsequently no constant values were obtained, but on judging from similar spectra, on one occasion the metal contained 0·95, and another time 0·65 per cent. of carbon. The sole change that had been made was due to the slit of the instrument having been cleaned. This indicates that it may be of some importance to have this so regulated by a micrometer-screw that its width may be accurately determined at any time during a series of observations. The temperature of the iron of the converter may have some influence upon the disappearance of the bands, as similarly bands already described appear during the "blow" more distinctly if the temperature is high than if it is low.

"Remarks on the Origin of some of the Lines and Bands observed in the Spectra from Swedish Bessemer Works."  
By W. N. HARTLEY, F.R.S. Received April 1,—Read June 20, 1895.

The observations made at various Bessemer steel works in Sweden, as described in the preceding paper, are of particular interest, owing to the number of accurate measurements of bands and lines observed in different spectra of the flame during the progress of the "blow" when different varieties of metal are operated upon.

As the paper was written, as I have been informed by Mr. Lundström, about nine years ago, the author was at a disadvantage in being unable to compare all his measurements with flame spectra of known origin at high temperatures. Fallacious deductions are liable to be drawn by referring bands and lines in the Bessemer flame to only such spectra as have been obtained by the arc or spark. This was found to be the case in the study of oxyhydrogen blow-pipe spectra ('Phil. Trans.,' vol. 185, A, p. 161); hence I propose to offer

FIG. 1.



- I. Beesmer spectrum from Långshyttan.  
 II. " " " Nykroppa.  
 III. " " " Ulfshyttan.  
 IV. Spectrum of the blue flame at Långshyttan.